



Formula 1 Technology

Formula 1 racing is an exhilarating blend of man and machine – but it takes a special kind of technology to be able to drive Formula 1 racers to glory. Mike Bedford goes behind the wheel and reveals the true champions of the fast lane

ALL PHOTOS AND SCREENSHOTS SUPPLIED BY RENAULT F1

Thrills, spills, glamour: Formula 1 racing has it all. But what makes a winner? A steely determination, perhaps; the ability of the driver to keep his cool while driving at high speeds, certainly. Computational fluid dynamic software and high-end workstations probably aren't the first things to spring to mind, or the second, or even the tenth. But they'll be top of the wish list for all Formula 1 teams when the 2006 season kicks off on 12th March in Bahrain.

Being one of the world's best drivers isn't enough to ensure success. Consider what happened with Michael Schumacher, who entered last year's season as reigning world champion. He held the title no fewer than seven times, and won 13 races in the 2004 season. Yet in 2005 his Ferrari made the top spot just once. What's more, that one race was the ill-fated US Grand Prix in Indianapolis where, due to a fiasco with the tyres, only six cars took part, four of which came from the lowly Jordan and Minardi teams. To add insult to injury, the Ferrari team finished the season in third place, with barely more than half as many points as Renault. Meanwhile Renault, at the close of season, had won eight out of 19 races. Fernando Alonso became the youngest ever Formula 1 World Champion when he brought his Renault home in third place at the

Brazilian Grand Prix on 25th September 2005. The team became Constructors Champions at the final race of the season in China.

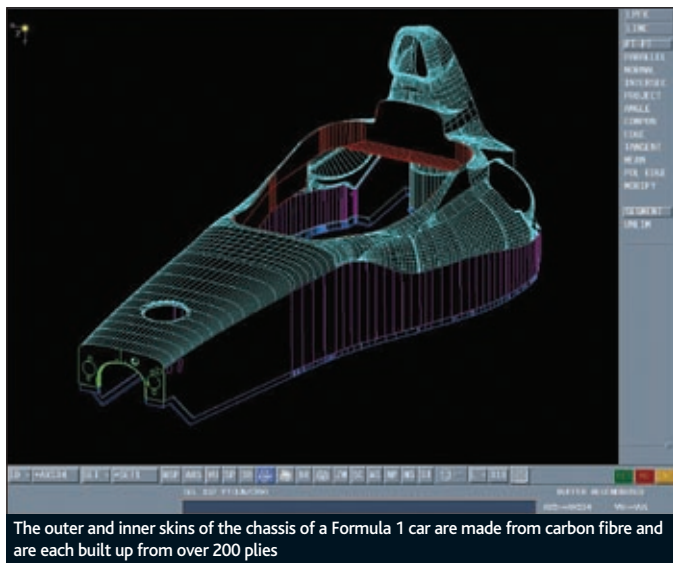
While Alonso's skill as a racing driver should not be underestimated, such facts as these suggest that success in Formula 1 requires a lot more than a quick racing driver. It is hardly plausible that a driver could lose his edge so dramatically in the space of six months. In reality, the driver is just a part of the complex equation that teams must solve to do well in Formula 1. Success also relies on acquiring and exploiting the technologies necessary to produce a better car and engine than all the competitors in the field.

Shopper went to the hallowed ground of Renault's Whiteways Technical Centre at Enstone in Oxfordshire to find out how the technology works.

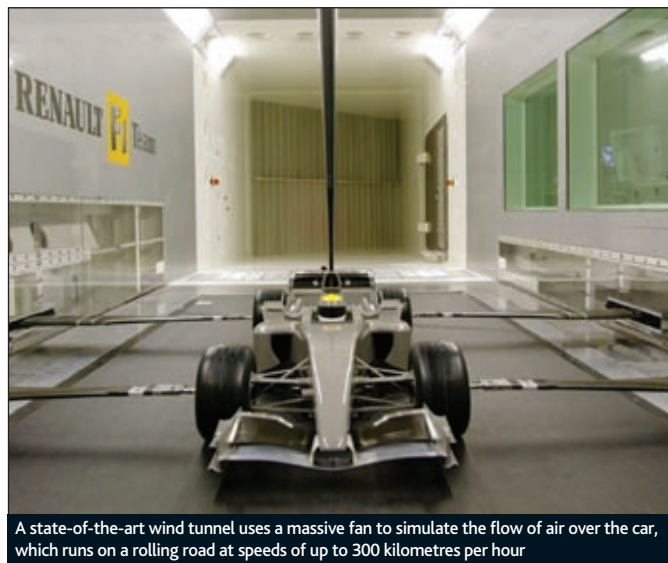
DRIVEN BY DESIGN

The forthcoming Bahrain Grand Prix has been eagerly anticipated by the millions of Formula 1 fans who haven't seen their heroes battle it out since last October. Behind the scenes at Enstone, though, the closed season isn't that quiet. Since the conclusion of the 2005 season, engineers have been perfecting the R26, the car they hope will do this year what its predecessor managed during 2005.





The outer and inner skins of the chassis of a Formula 1 car are made from carbon fibre and are each built up from over 200 plies



A state-of-the-art wind tunnel uses a massive fan to simulate the flow of air over the car, which runs on a rolling road at speeds of up to 300 kilometres per hour

If you think a design office is just rows upon rows of drawing boards, think again. Neither is a computer that runs computer-aided design (CAD) software the electronic equivalent of a drawing board. Renault's design operation uses a CAD solution called CATIA from Dassault Systèmes, plus an army of over 50 specialists generating terabytes of data each season.

While gains in productivity and ease of use are important, they are just the tip of the iceberg. For a start, CATIA is integrated with a Virtual Product Manager system for data management. This allows individual parts to be grouped into a key assembly, which is a family tree that makes up the car. Components aren't designed individually but within the context of – and constrained by – neighbouring parts. There are other benefits to the CAD approach.

Carbon fibre is as strong as steel yet it's four times lighter, so clearly it's an important material in the construction of a Formula 1 car. However, it's not the easiest material to work with as it has to be

built up from dozens of layers, or plies. Technicians lay these plies in sequence, following exact instructions for their placement, orientation and starting point. Doing this in the traditional fashion is a labour-intensive and time-consuming process. Furthermore, it's very difficult to verify the strength of the part before its manufacture. To assist in the design of carbon fibre parts, Renault uses Vistagy's

recent introduction of FiberSIM has revolutionised the process. CAD engineer Alan Duerden described how things used to work. "Formerly, technicians created the patterns by laying sheets of paper on the completed chassis mould and cutting the papers by hand, adding any necessary darts or splices in the process," he said. "Manufacturing engineers would then enter the pattern data into the CAD software

for controlling the cutting machine.

With FiberSIM the engineers create most of the flat patterns directly from the CAD model. The engineers plot the pattern on to template film.

But prior to sending the complex templates to the automated cutting machine, they check them with a

laser projection system that projects on to the assembly the exact points at which each ply is to be fitted."

In 2005, engineers successfully used FiberSIM to create 40 templates that accounted for 152 plies, 78 per cent of the plies on the outer skin of the chassis. "Given the complexity of a Formula 1 chassis, that 78 per cent figure was impressive," said Duerden. "Normally I would expect as many as half of the templates to require major rework on the tool."

USE THE FORCE

If you have more than a passing interest in Formula 1, you'll be aware of the importance of aerodynamics in optimising a car's performance. Aerodynamics for a road car means making it slip through the air more effectively, thereby improving fuel efficiency. But in Formula 1, a prime consideration is achieving the down-force that helps cars corner faster than any other machines available in the world.

Wind tunnels were first brought to the sport in the late 1970s and they perform an essential role in aerodynamic testing. Costing millions of pounds, a state-of-the-art wind tunnel uses a massive fan to simulate the flow of air over the car, which runs on a rolling road at speeds of up to 300 kilometres an hour. But in the realm of aerodynamics, the new kid on the block is computational fluid dynamics (CFD) software. For more details on this, see the box titled Computation Fluid Dynamics on page 214. CFD packages perform computer simulations of the flow of a fluid – in this case, air – over a

The driver is just a part of the complex equation teams must solve. Success also relies on the technologies necessary to produce a better car than competitors

FiberSIM, which operates as an add-in to CATIA.

To see how it works, we'll look at the chassis, the largest component in a Formula 1 car. At its core is a combination of aluminium honeycomb and a resin-coated paper called Nomex. However, the outer and inner skins are made from carbon fibre and are each built up from over 200 plies. The

SELECTIVE LASER SINTERING

The technology that tests Formula 1 parts to the limit

Like all types of 3D printers, an SLS machine builds a model slice by slice. The software turns the three-dimensional CAD model into a series of slices that can be processed by the SLS machine. The thickness of the slices corresponds to the size of the pixels in ordinary 2D printing; the thinner the slices, the less obvious the jaggies and the smoother the model. Renault's top-of-the-range Sinterstation Pro has a slice thickness of 0.1mm, which corresponds to 250 slices per inch.

To start, a layer of powder is deposited on the bottom of the tank in which the object is built up. A laser beam traces out the shape of the bottom slice of the model in the powder. The Sinterstation Pro has a 70W CO₂ laser generating an infrared beam to heat the powder locally. The result is a process called sintering, a fusing of the particles

of the powder to form a solid. Depending on the powder, the solid could be metal, ceramic or plastic. Another layer of powder is then deposited on top of the first layer, which has been partially solidified, and the process is repeated. This continues, layer by layer, until the whole object is completed.

The part isn't ready to be used in a race car yet, though. When it first comes out of the Sinterstation, it hasn't reached full strength because the sintering has been superficial. Great care is needed to clean away the unsintered powder from all the nooks and crannies. The final stage is to bake the part in an oven to complete the sintering process and so give the part the strength it needs to be subjected to the rigours of life in the fast lane.



TECHNOLOGY AND THE WORLD CHAMPION

Shopper interviews the reigning F1 World Champion, Fernando Alonso

Computer Shopper: How much of your success do you put down to computer technology and intelligent onboard systems, and how much to your skill?

Fernando Alonso: It is very hard to divide everything up. In Formula 1, you need a package to win; the human elements and the technical elements working together perfectly. But one thing is true: a good driver cannot do anything without the right car. You cannot win without the car. So maybe the technical element is even more important.

CS: Which aspect of computer technology and onboard intelligent systems do you feel played the greatest part in catapulting you and Renault to the pinnacle of achievement in 2005?

FA: There is not one single technology – if there was a magic answer, everybody would do it, and they would all be winning. Having technology is not the key, really. It is how you use those tools. For the driver, this is true – you need to make the best use of the car, to understand it, and perform when you need to. And the same is true for the technicians. Renault has beaten teams with bigger budgets, and it is because we have been able to

find the right technologies and use them in the right way.

CS: So which technologies will keep you at the top in 2006?

FA: Everything! Every year, we work to develop a new car, to improve in every area, to use the technologies to do more. We will have done more simulations, more development, used more computer power in the design process, used more advanced technologies for the production. With the car, our engineers will bring new software and different systems every time. I think we had new software at every race in 2005, and that will be true again in 2006. Winning is about putting thousands of little elements together into a winning package.

CS: Do you ever wish you could have competed in the days before computing and intelligent systems, when it was more a pure test of the driver's skill?

FA: No, I don't. Some people say that technology makes the cars easier to drive, but I don't agree. We have traction control, or semi-automatic gearboxes,



F1 World Champion Fernando Alonso recognises the necessity of the perfect balance of skill and technology in Formula 1 racing

but we are still performing to the limit and the systems mean that the limits are pushed back even further. So we are performing more on the edge. That is what I love doing as a racing driver and technology helps me do that. Formula 1 is still a very pure test of the driver's skill, although I think we use a different range of skills and need to understand more systems than in the past. But in the end we are doing the same thing: driving to the limit. No matter what systems you have, that is a thrilling challenge.

structure, the shape of which is imported from the CAD system.

To see how CFD can improve the design of a Formula 1 car, we have to look at how CD Adapco's STAR-CD has been used to help slow the car down. Making a car go fast in a straight line isn't difficult; making one that can get round corners in the shortest time possible is more of a challenge. To the driver, the secret lies in braking as late into a corner as possible, but this requires the brakes to provide optimum performance. "When an experienced racing driver first drives a Formula 1 car, their first comment – almost without exception – concerns the power of the brakes," explained Pat Symonds, Renault F1's executive director of engineering, "A modern Formula 1 car can achieve 5.5g [five-and-a-half times the force of gravity] under braking, whereas even a high-performance road car probably won't reach 1g." (Note that 'g' does not refer to grams but is a measurement of gravity.)

The brakes of a Formula 1 car can provide brutal deceleration, slowing a car from 200mph to 50mph in three seconds. To achieve this sort of performance, the brakes get very hot indeed. Brakes can reach 1,200°C during a corner. At this temperature – sufficient for them to glow red – brake wear due to oxidation is an issue. Brake cooling is paramount. Cooling ducts force air over the brake pads while the car is on the straights, but the size of the ducts is crucial since larger ducts mean increased aerodynamic drag.

Not all circuits require the ultimate in brake cooling, yet the largest cooling ducts can cost 1km/h of top speed, more than enough to hand victory to a rival. "Achieving braking performance alone is easy, as is minimising the aerodynamic

penalty, but the secret is to achieve maximum braking performance and minimum aerodynamic losses simultaneously," said CFD team leader Matthew Laight. "For pure aerodynamics work CFD complements wind tunnel analysis, but [for] brake cooling it's the only viable tool."

The technical description of CFD in the Computational Fluid Dynamics box on page 214 reveals a processor-intensive operation. So what sort of computing muscle can a team bring to bear? Just over a year ago, Sauber Petronas made a big fuss about its latest supercomputer, codenamed Albert, which it claimed is the fastest in Formula 1. Built by Dalco and used for CFD, it cost £2.25 million and contains no fewer than 530 64-bit

AMD Opteron processors. This absolute beast of a computer is housed in 10 cabinets, each 2.3m high, 1.2m deep and 1m wide.

FROM CAD TO CAR

Wherever you see the word CAD you'll frequently see the word CAM, which stands for computer-aided manufacturing, and often the two terms are written as one word: CAD/CAM. There's a reason for the link. By transferring files straight from a CAD system to the automated manufacturing equipment, a part can become reality within minutes of it first appearing onscreen. Renault's Whiteways Technical Centre has no shortage of computer numerically controlled (CNC) machine



3D printers, or advanced digital manufacturing machines, add parts together to build up a complete object



tools, five-axis machines and machines for cutting carbon fibre plies. Five-axis machines are what most people think of as industrial robots, the mainstay of car production plants all over the world. But this isn't the ultimate; in fact, it is far from it. There may be no viable alternative for some parts, but in other areas there are machines that can fabricate components seemingly out of thin air.

Despite the success of CFD, it remains a time-consuming process because of the vast amount of number crunching involved. Wind-tunnel testing is much quicker, but it requires real parts to be made first. Since each technique has its advantages and disadvantages, they are used together.

To overcome some of the difficulties of preparing parts for wind-tunnel testing, so-called 3D printers (also known as advanced digital manufacturing machines) from 3D Systems are used to keep the wind tunnel running at all times. A milling machine or a lathe starts with a block or cylinder of metal and gradually removes parts until the necessary shape remains. These 3D printers do the exact opposite. Just as a 2D printer (such as a laser or inkjet) builds up a two-dimensional image by applying ink or toner to a blank piece of paper, a 3D printer is used to build up a solid object from nothing.

Renault uses stereo-lithography (SLA) machines to manufacture parts for wind-tunnel testing. These machines build up parts slice by slice in a huge tank of resin, using a steerable laser beam to cure the polymer, thereby turning it into a solid. Solid parts materialise within the tank of liquid. Bob Bell, the technical director of the Renault F1 Team, said there have been huge benefits from this approach. "Using digital manufacturing, we can make not just one but multiple parts within 24 hours, all with slight differences," said Bell. "Take as



▲ The Step 11 control system developed by Renault and Magneti Marelli can often do in a single instruction what it would take a general-purpose processor many instructions to perform

an example the end plate of the front wing. It's got what we call a 'flick' in it with thickness and shape. It's evolved to that shape because we've tested hundreds of variations. That flick will have been tested in 10 different lengths, 10 different angles and 10 different trims on each angle. That would take months of traditional model making."

But 3D printers aren't used only for wind-tunnel testing. In Renault's Advanced Digital Manufacturing Centre, selective laser sintering (SLS) machines are used to manufacture parts that will be used on the race cars.

In Formula 1 there's sometimes no alternative to adopting a 'just in time' approach. It is not uncommon for someone to fly out to a race with a new part that engineers fit to the car just before the first qualifying session. With 3D printers, it would be possible to go one further. There's been speculation that in future, a team could take a 3D printer to the track. Then it would be feasible for a CAD engineer, back at HQ, to finish work on a new part just an hour or two before it's needed and email the definition for onsite manufacturing.

RIGHT ON TRACK

It's race day, and all those man hours and computer hours of design, simulation and manufacture are about to be put to the test. The cars are on the grid and the TV crews are jostling to get a few last words with Alonso, Räikkönen and Schumacher before the pit crews and media are banished from the track. But this doesn't mean the technologists, engineers and computer scientists hand over to the drivers alone. Computer technology is every bit as important on this day as it has been throughout the winter months of testing and preparation in Enstone.

For a start, the cars are awash with electronic systems, many of which rely on computer technology. Renault uses a state-of-the-art control system called Step 11 to take charge of all the car's main functions. This was developed in conjunction with Magneti Marelli, and first used during the highly successful 2005 season. Measuring just 250x142x75mm, this black box barely hints at what lies inside. Yet according to Renault, it has the power of 10 desktop PCs. In reality this isn't comparing like with like, because the Step 11's 12 processors are special chips called digital signal processors, or DSPs. These processors are optimised for processing digital signals, an essential element in control and data logging. The headline speed might not sound particularly impressive at a total of 2,000mips. However, DSPs can often do in a single instruction what it would take a general-purpose processor, like the one in your PC, many instructions to perform.

Automatic gear boxes were banned a few years ago, but the method of gear changing on a Formula 1 car is very different from that on most road cars. The driver might initiate the process as the rules require – specifically by activating a paddle on the back of the steering wheel – but then the Step 11

COMPUTATION FLUID DYNAMICS

How number crunching is used to test Formula 1 cars

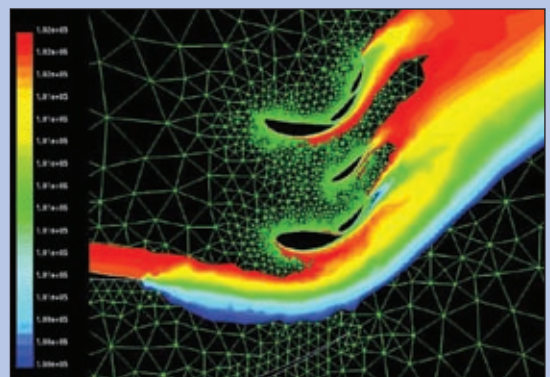
Computation fluid dynamics involves solving the equations that govern the flow of a fluid and associated heat transfer. These flows are continuous, but solving the equations by computer can be carried out only for fixed points in space. So the first job in any CFD exercise is to divide the area to be simulated – say the area in the immediate vicinity of a Formula 1 car – into a mesh of three-dimensional cells that, between them, encompass the entire volume being studied. Because lots of small cells come closest to reality (a continuity), the most accurate results require a super-fine grid comprising a large number of cells.

The differential equations that govern fluid flow and heat transfer have to be solved for every cell in the mesh. However, except for those cells at the edge of the grid, where so-called boundary conditions (known values) come into play, solving the equations for each cell requires knowledge of the neighbouring cells. This may seem a chicken-and-egg situation. For example, solving the equations for cell 100,231 requires the solution to cell 100,232, and a solution to this cell requires the results from cell 100,231. But all is not lost.

We need to start off with the boundary conditions for the perimeter cells and some arbitrary values for all the other cells before solving the equations across the mesh. Because most of those initial values would probably be far from the true values, the result will be wildly inaccurate. But the values will be slightly closer to reality than the initial guessed values. The next step is to carry out the whole process again, this time starting with the results from the first pass. Again, the results will be way out, but they will be just that little bit closer than they were the first time round. This process continues, over and over again, until two subsequent runs give near-identical results. Then the model is said to have converged and the results will be accurate.

Stephen Ferguson of Renault's CFD supplier CD Adapco gave us an idea of how much number crunching is involved when it comes to the size of a typical mesh. "For a full Formula 1 car, the big boys are now expecting 100 million

cells." For each of those cells, it transpires, four or five differential equations have to be solved. But this doesn't begin to hint at the amount of work involved, since we haven't considered the number of passes needed to achieve convergence. According to Ferguson, we're talking of around a thousand iterations.



Equations are solved by a process of gradually narrowing down the results until the model has converged



unit takes over. In just 10 milliseconds it declutches, switches on the rev limiter, rotates the shaft inside the gearbox, checks that the correct gear has been selected, engages the clutch and switches off the rev limiter.

TELEMETRY IN ACTION

In computing terms, something measured in milliseconds may sound pedestrian. This is because the electronics must wait for mechanical actions such as gear selection to take place. But in other areas Step 11 works much more quickly. Scattered about the car are around 50 sensors that measure various temperatures, pressures, the fuel level, brake wear and more besides. From this apparently small number of sensors, it's possible to log over 1,000 channels of information, some of which are measured directly, the others being calculated. The driver is able to keep an eye only on the information that's essential to driving the car. The LCD panel on the steering wheel shows the rev count and a handful of other measurements, chosen from the 48 available; usually lap time, speed and fuel consumption figures are chosen. Beyond this, it's down to an army of engineers in the team's garage, and this is where telemetry comes into play.

Like WiFi, telemetry involves transmitting data via a radio link, but there the similarity ends. An 802.11g link may have a range of a few hundred metres but an F1 car, at the most distant on-track position, can be two or three kilometres from the pits. However, Richard Marshall, chief electronics engineer, has managed to bridge the gap. "I got a WiFi link working reliably over 800m, but it took a directional antenna attached to the adaptor and an external antenna at the far end attached to the access point," he said. "Neither end was moving, though, and certainly not doing 300kph. I suspect most WiFi users have a lot less than the 100mW ERP power allowed by legislation, as the antennas built into PCs don't look that efficient. We have a good antenna position on the car, the same at the other end, and more transmitter power. So you start to see why we get much further."

To overcome the disruption that can be caused by multiple reflections of a signal transmitted from a fast-moving car, the modulation method is similar to the one used

BACK TO THE FUTURE

What place do computers have in the future of Formula 1?

Today it's hard to envisage Formula 1 devoid of technology – especially computer technology – as it is surely the most technological of all sports. But it hasn't always been like that, and if certain activists get their way Formula 1 will one day return to its roots.

You can think of the debate as a 'poacher and gamekeeper' model in which the FIA, Formula 1's governing body, acts as the gamekeeper. The FIA's desire seems to be to return to a more simplified form of F1; however, the belief of the teams is that you cannot un-invent technology, hence the ongoing debate about technology levels. But less technology doesn't always mean less

money. Changing the rules means changing the technology, and this costs a lot of money. With teams aiming to keep their budgets in check, you can see why this debate is one that will run and run.

However, certain technologies that were first pioneered in Formula 1 have already been consigned to the history books – thanks to rule changes – though some are starting to turn up on road cars. Launch control, intelligent automatic transmission, active ride suspension, ABS and pits-to-car telemetry are just some of the technologies that appeared in the 1990s but may never again see the light of day in an F1 car.

for digital audio broadcasting, which is immune from these multi-path effects.

Back in the pits, applications are churning through the huge volumes of data streaming in from the car. Here, too much information can often be more of a problem than too little, as IT manager Graeme Hackland explained. "To prevent information overload, the software filters the information, presenting it in an easy-to-understand format, ensuring that each engineer sees only the data necessary to monitor the parts of the vehicle for which he has responsibility."

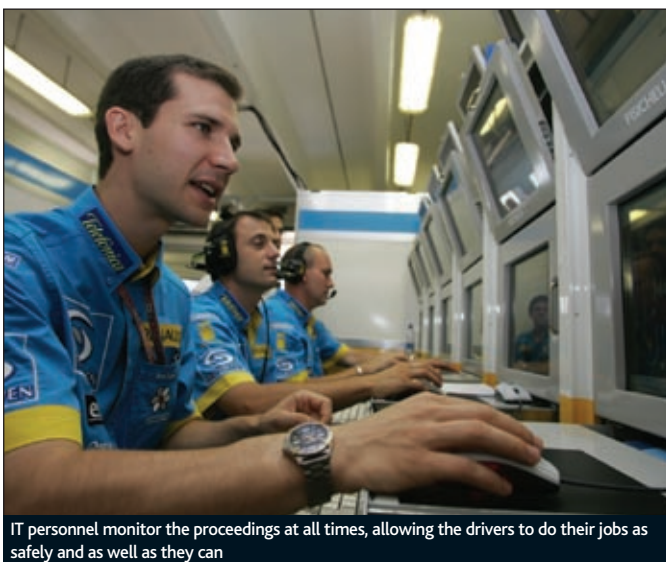
To get the ultimate from a race car, a delicate balance must be struck between performance and component life. Many of the components in a car are designed to last for just one race, although rules now require the engine to last for two. Rarely does a part fail without some notice, though, and often remedial action can be taken if the symptoms are spotted early enough. A high rate of brake wear undoubtedly means a driver can't brake quite as late into a corner as he would otherwise, but being forewarned might make the difference between easing off and narrowly holding on to a lead, or spinning off and ending up embedded in a tyre wall. Hackland told us: "An F1 team has two great assets: people and data. The job of the IT resources

and structures is to allow those talented people to create, store and manipulate that data as seamlessly as possible." This effective use of real-time data by engineers off the track to advise the men in action on the track is a perfect illustration of this underlying principle.

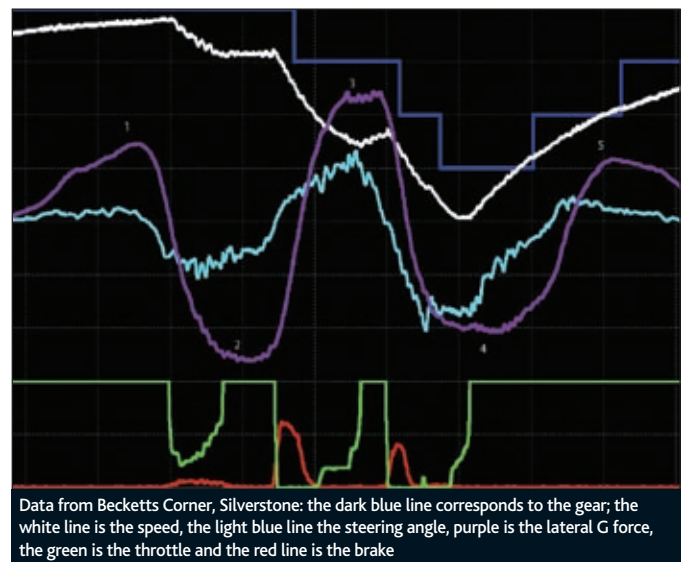
RACING CERTAINTIES

In computing we're used to an ever-increasing rate of change. Processors double in speed every two years and, in a similar time interval, memory chips double in size. For the Renault F1 Team, working within tightly controlled technical regulations, improvements are harder to come by. Aerodynamics, tyres and engines aren't subject to the same exponential rate of growth. A year-on-year improvement of one or two per cent is considered substantial, even with the greater computing resources afforded by Moore's Law.

There are nine teams and 18 drivers intent on denying Renault what it achieved in 2005. Each one of those teams is committed to making the most of what digital technology has to offer; Sauber Petrons' new supercomputer is evidence of that. It has been said that technology has robbed Formula 1 of excitement. Not from where we're sitting. **CS**



IT personnel monitor the proceedings at all times, allowing the drivers to do their jobs as safely and as well as they can



Data from Becketts Corner, Silverstone: the dark blue line corresponds to the gear; the white line is the speed, the light blue line the steering angle, purple is the lateral G force, the green is the throttle and the red line is the brake